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Is it all about Information? The Role of the Information Gap between Stakeholders in the Context of the Circular Economy

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Abstract

There is still a big difference, between a circular economy as described in the literature and reality. All this can be attributed to one reason: An information gap within the circular economy. The information is available, but not exchanged between the stakeholders. In this paper, we discuss the role of the information gap, present solutions for bridging this gap and introduce some key components to promote an advanced circular economy.

Keywords: Circular Economy; recycling; information marketplace; information loss; sustainability engineering; intelligent systems; Industry 4.0; Recycling 4.0

1. Introduction and Motivation

The Circular Economy (CE) has various definitions in the literature. Kirchherr et. al. found 114 different definitions of CE in scientific publications. In contrast to end-of-life concepts, CE is a system that replaces it with a concept of reduction in consumption, reuse of products or components as well as recycling. Among the strategies that make a CE possible is the extension of product lifetime, product repair, remanufacturing, component reuse, second-life applications, or optimized collection programs and recycling technologies. This makes it possible to achieve sustainable development that creates economic prosperity, allows ecological goals to be achieved, and ensures social justice [1]. Consequently, the concept of CE is accordingly recommended or practiced by various institutions like the United Nations for instance or states such as China or the European Union [2], [3], [4].

However, if we have a look at the status quo, there is still a big difference between the CE described in literature and reality. Smartphones are built to be irreparable, at the end-of-life of a lithium-ion battery, it is not possible to make informed decisions about the depth of disassembly, and recycling companies do not have an overview of the materials the products contain. All this can be attributed to one main reason: *an information gap between all stakeholders involved in the CE* [5], [6].

Figure 1 shows an overview of the relationships described above. In the center is the CE product that implements the strategies of the CE. Around the CE product, the most important stakeholders are shown. During the product life-cycle, all stakeholders, are at a certain point in time, also owners of the product or components or substances containing the product. In this context, the stakeholders are all part of the CE, but separated by information gaps. The information is available, but there is no exchange between the stakeholders.

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There are several reasons for this, sometimes companies try to protect their competitive advantage, and sometimes there is no relationship between stakeholders.

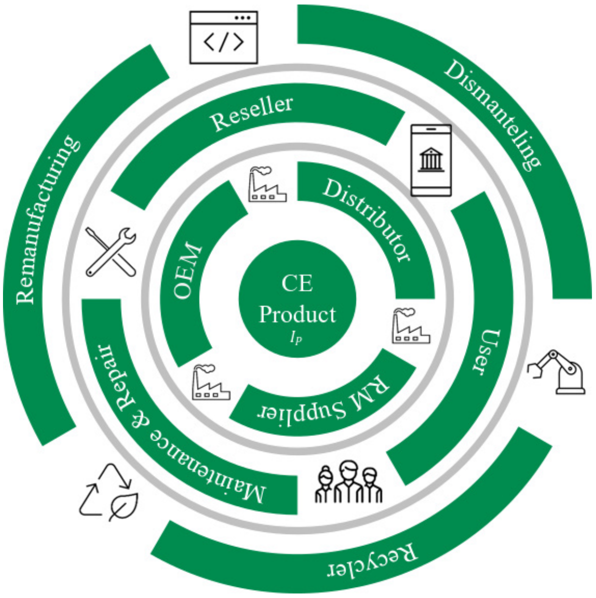

Figure 1: Overview about the different stakeholders in the Circular Economy and the information barriers (grey) between different layers of use

Therefore, this paper aims to identify the information gaps that exist in a CE and to show techniques to close these gaps. For this purpose, an information marketplace, as well as a database containing information on existing recycling technologies, is recommended.

The rest of the paper is structured as follows: Section 2 describes the effects of information within the CE. We show the relevance of information in a CE and illustrate the different types of information with an example. We use a mathematical model to describe the relationships between the different types of information and the loss of information. Finally, we show the difference between real information within the CE and an ideal status and explain the reasons for the difference between the real and ideal status. In Section 3, we discuss approaches to minimize information loss. First, an information marketplace and then a recycling technology database will be presented to overcome the information gap. Section 4 discusses the proposed concepts from the perspective of three stakeholders. Finally, we provide recommendations for the implementation of our approaches to close the information gap and thus create a more effective CE. A short conclusion and outlook conclude this paper.

2. Impact of information on the Circular Economy

Nobel Prize winner Ronald Coase has already pointed out that in an ideal market, the definition of property rights leads to a Pareto Optimum. In this state, no market participant can improve his position without weakening the position of another. In such an optimum no transaction costs are to be carried out, to which the procurement and the analysis of information count in addition. In an ideal market, or in this case an ideal CE all participants must therefore be informed completely, simultaneously, and without cost. In a real market, these assumptions are obviously utopian. It can be concluded that a lack of information must be prevented, to save costs [7].

2.1. Fundamentals: Data, Information, and Knowledge in the Context of the CE

The term *information* is defined differently depending on the scientific field. In this paper, we define information in the context of information theory and computer science. Based on the **D**ata **I**nformation **K**nowledge **W**isdom (DIKW) pyramid, Data are symbols representing the properties of objects, and Information is data in a specific context [8], [9]. Knowledge represents the interpretation of information[8], [9].

Information is associated with data and represents the properties of an object in a context [10], which is the CE in our case. Here, information represents the attributes of a CE product. CE products represent all products that are not made for single-use (e.g. Coffee-to-go Cups) but should be kept in circulation, as long as possible. These attributes can either be static information or dynamic information. Static information describes properties that are constant and unchangeable over time, while dynamic information evolves and is enriched over time. The latter includes dynamic information such as the age, the condition of a product, or repair procedures. Static information includes for example information about the date and place of production of a mobile phone or the chemical composition of a battery, and product information. Product information can be any information that describes the product. The manufacturer, current user, raw materials used in the product, etc. are just a few examples. Dynamic information, on the other hand, is only generated over time, such as the replacement of some parts, or the operation hours.

However, some of the information is lost during the lifetime of a product. The reasons for this are diverse, manufacturers take the products off the market or go bankrupt, supposedly important information is classified as irrelevant, or sometimes it is simply poorly documented. Another reason is poor communication between the stakeholders or different owners of a product. Especially dynamic information is lost because they was never documented. Without this information, an optimal decision in line with the overall goal of the CE is not possible [6].

Table 1: Description of the used variables and indicators

Variable	Explanation
I_{CE}	Set of Information related to a CE product. This Set describes the ideal amount of Information
I_s, I_d	Set of static and dynamic information, respectively
i_s ,i_d	Static or dynamic information objects, respectively
OEM, User, Recycler	Indicator for OEM, User, Recycler who owns the CE product
LoI	Loss of Information
T	Time unit
t	Operating Time

2.2. Information Flow Example and Loss of Information over Time

The goal of this subsection is to show the information flow over time by introducing a short example of a life-cycle for a CE product. Therefore, we developed a theoretical model, which formalizes the information flow over the time and shows especially the loss of information. Table 1 shows an overview of the variables we are introducing. Our model is necessary to illustrate the interrelationships of different types of information between the different stakeholders within a CE.

Initial Situation: To demonstrate our scenario we use a small setting about the life cycle of a *CE product*. As shown in Figure 1, we have a set of different stakeholders in the circular economy. For our setting we consider three stakeholders:

- Original Equipment Manufacturer (OEM): Produces the CE product and sells it.
- User: Individual who owns the product for a certain period of time.
- Recycler: The Recycler finally will disassemble and recycle the CE product and needs therefore a couple of information.

Every stakeholder owns our *CE product*, for a certain period of time T_i, *where* $i \in \mathrm{N}$. The life cycle of our product begins with production by the *OEM* at T_0 (see Figure 2). At T_1, the *CE product* gets sold to the *User* (change of the ownership), and the latter holds the product for the longest period until the *User* hands it over to the *Recycler* at T_2.

Fundamentals: To understand the behavior of the information over time, we first introduce the differences between *static* and *dynamic information,* formally. Every *CE product* contains a set of *static information* and *dynamic information* (Eq. 1). Each set contains information objects i, which is an unspecified object that can represent any information that describes the CE object (Eq. 2 & Eq. 3). The set elements are heterogenous and unique (e.g. strings, dates, integers, etc.).

$$I_{CE} = \{I_s, I_d\} \tag{1}$$

$$I_s = \{i_s \mid i_s \text{ is a static information object}\} \tag{2}$$

$$I_d = \{i_d \mid i_d \text{ is a dynamic information object}\} \tag{3}$$

Static Information Flow: At T_0 i.e. the beginning of the life cycle of a *CE product*, the I_{CE} contains k static information objects, and it is complete. Accordingly, the *OEM* is aware of all information (Eq. 4).

$$\left|I_{s,OEM}\right| = \left|I_{s,CE\ Product}\right| = k \quad \text{where } k \in \mathrm{N} \tag{4}$$

In theory, the ideal set of static information is unchangeable, since no new static information objects i_s are added or lost (see Figure [2] $|I_{s,CE\ Product}|$).

But in reality, some information is lost, when the *CE product* changes ownership (see Figure 2 $|I_{s,real}|$). This loss is shown in equation 5 and 6:

$$f_T: I_s \to \{0, 1\} \tag{5}$$

$$f_T(i_s) := \begin{cases} 0 & \text{if } i_s \text{ is lost at point in time } T \\ 1 & \text{if } i_s \text{ is preserved at point in time } T \end{cases} \tag{6}$$

After manufacturing the CE product, its ownership will be transferred to the *User*. However, on the one hand, the latter will receive an incomplete I_s, mainly due to the reason that some information are company secretes of the OEM and will not be transferred. On the other hand, some of this information is important while some is irrelevant (for the *User*). At this point, the first information gap is visible (see Figure 2 T_1 & Eq. 7).

$$|I_{s,User}| \leq |I_{s,OEM}| \tag{7}$$

After using the product, the user will transport it to a recycling company. Often there is no direct contact between the user and the recycler. Hence the recycler will not receive a lot of information about the product from any of the previous stakeholders. The *Recycler* can only rely on information connected to the product directly. This implies that again information is lost when the owner changes (Eq. 8).

$$|I_{s,Recycler}| \leq |I_{s,User}| \tag{8}$$

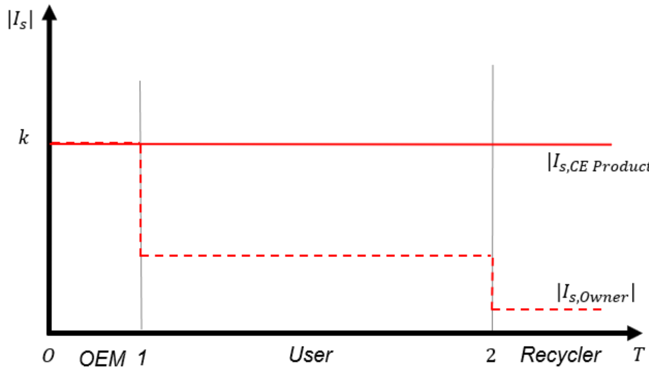

Figure 2: Static Information Flow

Dynamic Information Flow: At T_0, I_d is empty, because the CE product was not used yet (see Figure 3 & Eq. 9).

$$I_d = \{\ \} \tag{9}$$

Furthermore, the *OEM* will not create any dynamic information as long as the CE product is not used. The first dynamic information objects i_d will be generated by the *User* by start using the CE product. The generation of i_d depends on the operating time of the CE product t and will add to I_d (Eq. 10).

$$g: \mathbb{R} \to \mathfrak{P}_{I_d} \text{ with } \mathfrak{P}_{I_d} \text{ Powerset of } I_d \tag{10}$$

$$g(t_0) \subseteq g(t_1) \text{ if } t_0 \leq t_1 \tag{11}$$

Here is a difference, between the theoretical ideal information generation $I_{d,CE\ Product}$ and the reality $I_{d,owner}$, since usually not all theoretically possible information objects are captured. But, the real captured information in $I_{d,owner}$ is always a real subset from the (theoretical ideal) $I_{d,CE\ Product}$ (see Eq. 12).

$$I_{d,User} \subseteq I_{d,CE\ Product} \tag{12}$$

Moreover, when there is a change of ownership, not all captured dynamic information objects will be passed on to the new owner (same as for the static information in Eq 5 & 6). This *Loss of Information* (*LoI*) is characterized by the difference between the cardinality of the set of information (depending on the stakeholder). See Eq 13:

$$LoI = \left|I_{CE\ Product,T}\right| - \left|I_{Owner,T}\right| \tag{13}$$

Limitations: In the shown scenario some simplifications were assumed. For example, the behavior of the dynamic information flow is linear, which is not always the case. The generation of dynamic information objects always depends on the operating time t, as well as on additional environmental factors, which are not considered in the formulas yet (but part of our ongoing research). We just choose a linear behavior to decrease the complexity of our model, without reducing the importance of our statements and objectives. Moreover, the loss of information during the change of ownership was only sketched in abstract terms, as well as the difference between the $I_{d,CE\ Product}$ and $I_{d,owner}$. In the future, we want to consider not only the loss of information objects but also its falsification.

Lastly, another limitation at the current state is, the fact that we just consider dynamic information as a function of the operating time *t*. Dynamic information which the product itself cannot record, but which may be relevant, such as storage time and transport information, is not considered yet.

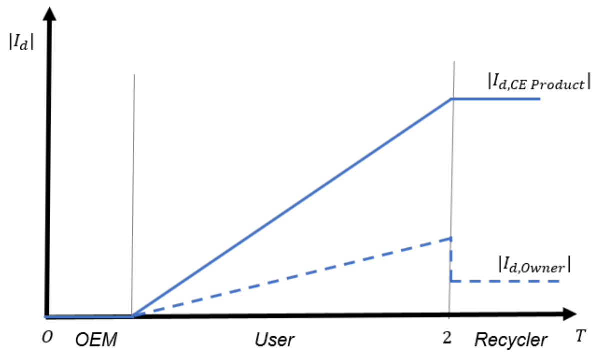

Figure 3: Dynamic Information Flow

2.3. Problem Summary and Problem Statement

As described above, according to Coase, information is the key to achieving a Pareto Optimum. In the previous example, static and dynamic information about the product is transferred from the old to the new owner when the CE product changes ownership. Ideally, no static or dynamic information will be lost. In reality, a constant loss of information during the change of product ownership counteracts the information gain (see Figures 2 and 3). As a result, the total information of a product can even be less than at the beginning of the product life.

Vision: Theoretically, the ideal information content can be generated by the existing static information as well as the generation of further dynamic information. With this ideal information content and a loss-free information content transfer to each stakeholder of a CE at any time, a Pareto optimum would be achieved according to Coase. The *LoI* would be zero.

Issue: However, since such an ideal information content cannot be generated due to e.g. company secrets, data protection, insufficient information collection, non-standardized and partly non-existent information transfer, and "not knowing" about the information that would have to be generated for an improved CE, there is a difference between the ideal and real information content.

Method: Therefore, methods are necessary to minimize the *LoI*. By analyzing the main reasons, and pain points for the *LoI* in our model. Especially, when changing ownership, important static information is lost and dynamic information is barely collected for various reasons. In particular, the stakeholders at the end of the CE (e.g. recyclers) are the ones who suffer. Therefore, we propose an information marketplace to exchange all the information along with the whole CE, and create incentives, as well as a legal framework for information exchange. A database regarding recycling technologies and processes bridges the exchange of information between the beginning of a CE product lifespan, and the end.

3. Closing the Information Gap in the Circular Economy

As elaborated in the previous sections, the success in achieving the CE depends mainly on the information provided. An OEM needs information for a mechanical design suitable for recycling, a user needs information on how and where to repair or recycle his device, and recycling companies need dynamic information to make a well-founded decision. These decisions include the main objectives of the CE: *Reuse & Resale, Repair & Remanufacturing, and Recycling.* Therefore, in the last section, we modeled an ideal flow of information over time for a CE product. But, as discussed earlier, achieving an ideal information content $I_{P,CE\ Product}$ is utopian. The goal of this section is to introduce solutions to minimize the *LoI* (especially in line with the main goals of the CE).

3.1. Information Marketplace

How to get access to information which we cannot acquire on our own? As explained in the previous sections, CE processes rely often on information from other (or previous) stakeholders. In a production process, there are well-established supply chains for challenges like these. But, beyond the supply chains, there is no need and no incentive for cooperation and networking. A comprehensive framework for this is still not established. Consequently, a comprehensive framework has yet to be established first. It could either be a political framework, which would be challenging due to globalization and the many different political laws, or a market-based framework. To overcome the political hurdles, we developed an information marketplace as an incentive and a framework for the exchange and trade of CE-relevant information.

An information marketplace provides a secure platform for the exchange of information between consumers and providers. It is necessary because there is no relation between the consumer and the provider, as long as they were not previously connected (for example in a supply chain). There is a lack of trust between the participants. In this case, standards, regulations, laws, and contracts for trustees are often placed between the parties [11]. These are provided by our marketplace. As a result, all stakeholders just have to create trust in the information marketplace. As a result, the information marketplace provides a perfect framework and platform to connect the stakeholders in the CE who have not previously had a (business) relationship before, such as a recycler with an OEM and the consumer, or a design engineer (from the OEM) with remanufactures and recycler.

Compared to existing data marketplaces, such as the German Mobilitätsdatenmarktplatz MDM, and Internet of Things or blockchain-based solutions like Streamr, our solution focuses on providing a reliable platform for all stakeholders of the CE. All the stakeholders have different technical background knowledge, and different levels of IT in their companies. These facts were taken into account in the design of the marketplace, as were challenges such as data- and information quality as well as integrity, and safety and privacy aspects. The architecture is designed decentralized, as described in our previous work [12]. Providers are supported by the metadata client with their offer description [13], and the consumers can verify the information against their specific requirements before buying [14].

3.2. Database Regarding Recycling Technology

The marketplace creates different possibilities for information availability as well as structuring these for easy access. Different modules can be created to best suit a certain stakeholder. Not all information is needed by every stakeholder. Hence, the modules must provide certain information to one stakeholder; based on the information provided by all other stakeholders.

Within a CE, the recycling approach is inevitable for all goods at its end. Thus, when developing a product, it is necessary to know which materials are already recyclable. A mechanical designer has to consider various design parameters. Information is needed to make comprehensible decisions within a methodical design approach.

With regard to CE, a recycling approach - a well-structured information database about recycling abilities of materials - has great benefits for the mechanical designer. The database should start with the materials which the mechanical designers use for their products. There are chemical elements that can be utilized; therefore, the database has to provide information on this very basic level of elements. By collecting already economically feasible recycling processes and structure them to the chemical element it is possible to create quickly accessible information regarding what the designer needs in a particular case.

Embedded in the periodic table of the elements this is the foundation for further development of the database. An example is metallic alloys, e.g. for steel, aluminum, etc., which are a combination of different elements. In the database, for every new alloy, a new layer is created, which is associated with the respective elements. The new database layer offers the possibility to integrate the recycling processes for alloys. This connection offers the possibility to shorten the recycling cycle by choosing the appropriate materials at an early stage.

A database also offers opportunities for companies developing recycling technologies. By including their methods in the database, their process becomes visible to the mechanical designer and therefore considered as part of their recycling strategy. Minor collaborations between recyclers and designers can arise through this information channel. The product under development will then better fitted for the recycling process. This could have a massive impact on recycling costs at the end of the product's life.

4. Discussion and Recommendations for Actions

The goal of this section is to show the advantages of our current solutions in the context of the CE. Therefore, we show first the main use cases out of the perspective of three chosen stakeholders. Furthermore, we discuss the limitations of our current solutions and provide some recommendations for actions to reach an advanced circular Economy.

4.1. Use Cases

In the following, we demonstrate some main use cases and advantages of our proposed solutions from the perspective of three selected stakeholders (in line with Section 2.2):

OEM: By providing mechanical designers access to a database containing information about recycling processes, recycling-oriented design can be considered even before the design process. Information in the database is static and time resistant. This will ensure that recycling relevant design decisions are made and at the same time the most important information for recyclers is collected

Users: For many CE products, the (end) users have been in possession of these products for the longest time in relation to the other stakeholders. Due to this long period of time, they usually cause the greatest *LoI*. However, in most information, they are not interested. The information marketplace creates incentives for users to collect and sell this information. Thereby, they have full control over their information.

Recycler: When a CE product reaches the end of its life span, important decisions have to be made (in line with the overall goals of the CE). Decisions about second life, reuse of components, or the right recycling processes. Both static information and dynamic information are relevant to these decisions. The information marketplace enables a way for recyclers to acquire this information, as well as to share their knowledge with the other stakeholders to improve the overall CE.

4.2. Discussion and Limitations

Right now, the solutions are focused on specific use cases, especially design for recycling and the recycling processes itself. The database enables access to information for the mechanical designer, as well as the recycler. It provides an option for the storage of recycling process information, which is independent of a specific CE product instance. However, the collection of other static information, such as the material composition, which is important from the beginning is missing. Here digital twins create remedy [5],[6], [15].

The information marketplace enables the option to sell access to the recycling database. Furthermore, dynamic information can be sold by different owners. This ensures that they are maintained and passed on. For example, a user can sell information about the period of use of a CE product, parts exchanged, and much more. The user can choose which information he is willing to share and which he is not. This way, he retains control and does not become a transparent user.

However, out of the scope of this paper were different questions discussed, such as how to collect the information in a user-friendly way, or technical challenges like different data formats and so on.

4.3. Recommendations for Actions

As already pointed out*: Information is a key component* to achieve an advanced circular economy. Without a well-founded information basis, no optimal decisions in terms of the CE are possible. Our framework for improving the exchange of information and for reducing the loss of information over time currently contains two main elements: An information marketplace and a database on recycling technologies. However, the following measures are necessary to establish the proposed advanced circular economy by us in the future, the following actions are necessary:

- The database as well as the information marketplace must be active, used, and maintained. Especially, for the recycling database, researchers must keep it up to date and bring new recycling processes into play.
- Both systems must be actively promoted and incentives must be created, especially for the end-users.
- Information and data standards are necessary to avoid semantical chaos.
- The platforms must provide data security and trust.
- A methodology for determining the information value is necessary.
- All stakeholders need technical support and easy access to the systems to provide their information.

Those recommendations are necessary to create a reliable functioning marketplace. The maintenance of the database leads to the most recent information for all stakeholders. If the information is not regularly updated, it is possible that another stakeholder may base their decisions not according to the standards of others.

By involving all stakeholders through the promotion of the marketplace, the necessary information is collected to establish the targeted CE. Therefore, the information has to have a specific standard and format for all users, so they can provide and receive information as easily as possible and become accustomed to a certain uploading process. Of course, the system has to be secure, so the stakeholders are willing to put their trust and information into the system. This will create the necessity to evaluate the value of the information and thereby creating an incentive for the stakeholders to offer valuable information if they receive equal or higher valued information in return.

In order to enable all stakeholders to provide information – if they are willing to so – an easy-access system has to be set up; if necessary, additional support must be offered, to decrease the system-inherent barrier, which is created by setting up the marketplace.

5. Conclusion and Outlook

The goal of this paper was to identify and explain the problem of an information gap in the context of CE. Therefore, we introduced the impact of information in CE and formalized the loss of the information during the product lifetime. By introducing three exemplary stakeholders from the CE, we analyzed their information needs. One of our main findings is that the information is lost over time, especially when a product changes ownership, and that we have to differ between dynamical and static information.

Our solution consists of an information marketplace, and a recycling database to decrease the loss of information over time, by providing simple systems and incentives for all Stakeholders in the CE. In summary, it can be said that our solutions pave the way for the transformation from a Circular to an Advanced Circular Economy.

In our future work, we will also show the value of information and its influence on the overall model and present the solutions in a more detailed way.

Acknowledgments

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